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Active Water Explosion Suppression System

Mark Anderson & Steven Wells, Applied Research Associates, Inc.
P.O. Box 40128
Tyndall AFB, FL 32403

Maj. Dov Dover, Israel Air Force

AIR FORCE RESEARCH LABORATORY
MATERIALS & MANUFACTURING DIRECTORATE
AIRBASE TECHNOLOGIES DIVISION
139 BARNES DRIVE, STE 2
TYNDALL AFB FL 32403-5323

NOTICES

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

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VIRGIL J. CARR JR., DR II, USAF
Leader, Fire Research Group

//signature//

RICHARD N. VICKERS, DR-IV, USAF
Chief, Deployed Base Systems Branch

//signature//

JIMMY L. POLLARD, Colonel, USAF
Chief, Airbase Technologies Division

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Within the military community there are many places where munitions are stored, handled, moved, worked with, tested, assembled, or disassembled. In each of these areas there is always the possibility of an unplanned detonation. The concept Active Water for Effective Suppression of Munitions Explosions (AWESOME) would detect an explosion event and would actively respond to it by triggering a projected release of water at the explosion or in the path of the pressure wave. This released blast of water would stop the explosion shock wave propagation at that point and would mitigate the blast effects at the specific point where protection from an explosion is desired. This work effort concentrated on designing an active water discharge system that could move large masses of water with a goal of exceeding 300 feet per second. Several methods were evaluated that minimized the quantity of explosive material required to move the water at desired velocities.

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EXECUTIVE SUMMARY

Within the military community there are many places where munitions are stored, handled, moved, worked with, tested, assembled, or disassembled. In each of these areas there is always the possibility of an unplanned detonation. The ability to stop an explosion's propagation by an active explosion suppression system would save lives, equipment, and facilities. Stopping an explosion in an explosive storage facility would keep other explosives from detonating as a result of the initial explosion’s blast effects.

The Air Expeditionary Forces (AEF) Technologies Division, part of the Air Force Research Laboratory (AFRL), at Tyndall AFB, Florida, has a research and development program to build a prototype active explosion suppression system based on past work accomplished by a number of military research and development organizations. The concept Active Water for Effective Suppression of Munitions Explosions (AWESOME) would detect an explosion event and would actively respond to it by triggering a projected release of water at the explosion or in the path of the pressure wave. This released blast of water would stop the explosion shock wave propagation at that point and would mitigate the blast effects at the specific point where protection from an explosion is desired.

Active water mitigation systems have potential to protect equipment, facilities and personnel in areas where deflagrations or detonations can occur. Current water discharge systems cannot provide coverage in a timely manner to mitigate these events. Therefore, previous work mainly concentrated on static water filled barriers to determine effects of suppressing or mitigating blast pressures. Field tests of explosion events showed that by placing the water containers in certain configurations around the explosion point that the shock wave resulting from the explosion was directed in various directions or dissipated at certain points. Thus, a water-blast mitigation system such as the envisioned AWESOME could be placed at a certain point and directed in a specified direction to dissipate an explosion' s shock wave and thereby protect a specific item, point, or feature.

In those areas where the likely of an explosion is possible, the system would have installed detectors directed at the point of possible explosive events. A prototype flame detector capable of detecting explosions in microseconds was developed at Tyndall, tested against explosions and was proven fast and effective. The speed of this detector could allow an active mitigation system to detect an explosion in the time required to trigger an active explosion mitigation system. Since his technology was proven, the decision was made to concentrate efforts on designing and initiating active water mitigation systems.

This work effort concentrated on designing an active water discharge system that could move large masses of water with a goal of exceeding 300 feet per second. The concept for a metal hemisphere extinguisher with a rubber diaphragm was developed to discharge large quantities of water as fast as possible. The 12-inch diameter hemisphere was constructed and tested.

The test effort ended by discharging water from the hemisphere extinguisher at a velocity of >230 feet per second. Several methods were evaluated that minimized the quantity of explosive material required to move the water at desired velocities. However, these methods were proven unsuccessful in this test series. The goal of delivering a large mass of water at high velocities was verified on a small scale in this effort.

Future efforts should build upon the lessons learned in this program. The implementation of explosively driven water should be optimized to determine maximum water velocities achievable and determine that the concept can be scaled up for larger mass flow. The shape of the water spray will also have to be optimized to effectively mitigate energy from deflagrations and detonations. Methods to increase water velocities and optimize water spray patterns include increasing explosive quantities, using shape charge expertise and developing steel, cone-shaped discharge orifices.

Evaluations against pyrotechnics and explosives will determine the level of protection from explosively driven water sprays. Assess fire protection of mixing bowl operations for pyrotechnics and infrared flare manufacturing operations to gauge the suppression effects of the developed system.

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I. INTRODUCTION

Within the military community there are many places where munitions are stored, handled, moved, worked with, tested, assembled, or disassembled. In each of these areas there is always the possibility of an unplanned detonation. Additionally, detonations of explosives may occur as a result of military actions against our forces or as the result of terrorist attacks against our facilities or people. The ability to stop an explosion's propagation by an active explosion suppression system would save lives, equipment, and facilities. Stopping an explosion in an explosive storage facility would keep other explosives from detonating as a result of the initial explosion's blast effects.

The Air Expeditionary Forces (AEF) Technologies Division, part of the Air Force Research Laboratory (AFRL), at Tyndall AFB, Florida, has a research and development program to build a proto-type Active Explosion Suppression System based on past work accomplished by a number of military research and development organizations. This concept development program would be based on the following research work efforts of the past.

First, work by the Navy at the Naval Civil Engineering Laboratory has shown that water blankets or water jackets around or near explosives can dissipate or mitigate the blast effects resulting from an explosive detonation. These passive systems are placed in the immediate vicinity of the explosive being worked on or moved and mitigate the blast shock wave by using the energy being generated by the blast to vaporize the water. The Navy work showed very favorable results during actual explosion tests[1].

Second, AFRL researchers at Tyndall AFB in the Fire Protection Research Group have in recent years developed for the U.S. Army Armament Munitions and Chemical Command (now the Industrial Operations Command) an ultra-high-speed fire protection deluge system. This system has been tested numerous times in the Tyndall laboratory and has effectively stopped deflagration of pyrotechnics, high explosives, and munitions propellants. The system reacts to the explosive event in the millisecond time frame and stops the explosive event before the blast shock wave or heat wave can generate[2,3].

Third, AFRL researchers at Tyndall AFB in the AEF Group have shown in full-scale field-testing (verifying the Navy's work) the protection afforded by water barriers, when placed near or around structures, from damage caused by terrorist-type explosions. The water barriers in these tests were, as in the Navy tests, passive barriers, which broke and allowed the vaporization of the water as a result of the explosion[4].

The concept Active Water Explosion Suppression System (AWESOME) would combine aspects of the above noted research efforts to build a system that would actively respond to an explosion event and trigger a projected release of water at the explosion event, stopping its shock wave propagation and mitigating the blast effects at a specific point where protection from explosions is desired.

A. Problem Defined

Working with munitions or explosive materials has always been a business that has associated with it the possibility of an unplanned explosive event. During the years between 1988 and 1992 the US Army's Industrial Operations Command has suffered a number of unplanned explosive events at various munitions facilities. These events have resulted in three deaths of munitions workers, nine serious injuries, and severe property and equipment damage totaling costs of $9,500,000 dollars. Contractors working with similar materials have also sustained additional losses as a result of unplanned explosive events.

In the case of terrorist attacks resulting in planned explosive events designed to destroy facilities, equipment, and personnel, there are numerous examples that could be cited in recent years to show the problem exists and that there is a definite need to provide a mitigating system that could prevent or lessen the damage from these attacks. Many lives and multi-millions of dollars have been lost as a result of recent terrorist attacks and the explosive events the terrorists have fostered.

The Navy noted in their paper the effects of an explosion in a confined space. A confined space is any place where the pressure wave from the explosion can be concentrated or trapped resulting in massive force or load being applied to walls, floors, or ceilings of buildings, or to various structures in a very short time span. When this happens the load applied to the structure can cause the structure to fail, sometimes in a dramatic fashion. Walls can be blown out, windows and doors can be blown out, debris can be projected from the site many thousands of feet, high temperatures can be generated causing fires, and structural integrity of the building can be compromised resulting in secondary effects such as collapse of walls and floors. Secondary explosions can result if the initial explosive event occurs in a facility where other munitions are stored or are being processed or worked on.

As noted in the Navy's paper, an explosion in a confined space causes the accumulation of high-temperature gases from the by-products of the explosion. These high-temperature gases, if expanding in a space with restricted venting, cause the buildup of gas pressures inside the structure. The magnitude of the peak gas pressure depends primarily on the weight of the explosive relative to the volume of the structure. The duration and total impulse of the gas pressure depends primarily on the degree of venting available for these gases to escape from the structure. The degree of venting, in turn, - depends on the area of openings and volume of space in the building envelope, the mass and strength of the building envelope, and the magnitude and location of the explosion inside the structure. The degree of confinement and venting in most facilities is sufficient to produce significant gas pressure loads inside the structure[1].

In the building and establishment of munitions storage facilities and ordnance handling facilities a concept is used known as "safe separation distance." This is a circle around an above ground structure of so many feet where no other structure can be placed within this circle. The circle is established around a structure based on the distance that debris may be thrown from an explosion that occurs within the structure. The force of the explosive event is based on the net explosive weight (NEW) of the ordnance or munitions being worked on or moved. Depending on the maximum NEW processed through the facility, a maximum credible explosion (MCE) is determined for the facility and the resulting safe separation distance is determined for the facility. The Navy paper gave an example of a facility processing ordnance with a NEW of 30,000 lbs or less. This resulted in a safe separation distance of 1,250 feet of clear space around the building[1]. While safe separation distances provide for explosive safety, they are extremely costly in terms of property lost to other uses. Mitigating an explosion event and reducing the separation distance needed between munitions storage or handling facilities will result in much more efficient and cost-effective use of expensive property.

While ordnance handling facilities and munitions assembly plants and storage sites would have known points of possible explosive events that could be protected, terrorist attacks could occur anywhere. The terrorist threat grows dally against United States targets around the world. Vital assets and personnel must be afforded the protection they need to survive a terrorist attack. Active explosion suppression systems could be placed at likely attack points, where the suppression of the blast would protect the building, equipment, assets, and personnel in the best possible manner.

1. Naval Civil Engineering Laboratory Work.

The work done by the Navy centered on what they termed the "water concept". As stated in their paper - The water concept requires water to be deployed in the near proximity, but not necessarily in contact, with the explosive material. The water must be in the near proximity of the explosive at all times when an inadvertent explosion is a credible event[1].

The water concept works due to the physical phenomenon of aerosolizing the water and thereby dissipating the energy developed by the explosion. Detonation of a high explosive produces high-pressure shock waves, which travel outward in all directions from the explosion at extremely high velocity. These high-speed shock waves strike and aerosolize the water located in the near proximity of the explosion. The aerosolized water prevents combustion of detonation products by preventing access to oxygen and by cooling gases below the temperature required to sustain combustion. For this to occur, the aerosolized water must absorb the detonation energy of the explosive. Typical heats of detonation for high explosives range from 980 calories/gram for TNT explosive to 2030 calories/gram for H-6 explosive. Vaporization of water absorbs 539 calories/gram plus one calorie/gram/degree to heat the water to 100 degrees Celsius. Thus, the aerosolized water can absorb all of the detonation energy of the explosive based on the weight ratio of water to explosive. For TNT this would be:

$$980/539 = 1.8 ,$$

and for H-6 high explosive:

$$2030/539 = 3.8$$

These ratios assume the aerosolized water is 100% efficient in eliminating the heat of detonation, thereby eliminating the heat of combustion and the associated burning of explosive by-products in the air. In practice, the weight ratio of water to explosive should probably be slightly greater than the above values to account for less than 100% efficiency in eliminating the heat of detonation. In any case, the net effect of the water absorbing the detonation energy of the explosive is a major reduction in the peak gas pressure and total gas impulse from the confined explosion[1].

Ideally, the shock waves need to aerosolize the water very quickly (in a matter of milliseconds) into a fine mist of water droplets suspended in the atmosphere of the containment structure. Hence, the need for the water to be located in the near proximity of, but not necessarily in contact with, the explosive producing the explosion. The water mist presents a huge surface area of water, an ideal condition for efficiently converting the water from a liquid state to a vapor state. The later-time buildup of high-temperature gases from the by-products of the explosion, expanding in a fully or partially confined space cause huge amounts of energy released by the explosion to be quickly dissipated by changing the water mist from a liquid state to a vapor state. The consequence of this phenomenon is a peak gas pressure and total gas impulse much less (as much as 90% less based on test data) than the peak gas pressure and total gas impulse would have been in the absence of water[1].

In the Navy paper, ten test results were summarized in a table showing the weight of the TNT explosive charge, the amount of water placed in proximity to the explosive, the arrangement of the water placement, the ratio of the water weight to explosive weight, and the resultant peak gas pressure reached as a result of the detonation. In each of the ten tests 4.67 pounds of TNT were used. Water weight varied from zero to 13.5 lbs, or ratios from 0 to 2.89. The average gas pressure for the two tests run without any water present was 54.1 pounds per square inch (psi). The average gas pressure for the two tests run with the 13.5 pounds of water present was 5.85 psi (these tests were using 3-sided water-filled cells around the explosive). This was nearly a 90% reduction in the explosive force of the blasts[1].

The findings of the Navy tests also showed that the manner of the placement of the water around the explosive made a significant difference in the maximum gas pressure resulting from the explosion. When the explosive was placed in a cube of water the mitigation effect approached the assumed 100% efficiency factor more closely than when the water was placed in water-filled cells on 3 sides of the charge. In tests using 9.0 pounds of water, the explosion in the cube of water produced a maximum gas pressure of 5.1 psi, while the explosion in the 3-sided water-filled cell produced a maximum average gas pressure of 7.9 psi. Both are significant reductions in the maximum gas pressure, but these results show that placement of the water makes a significant difference and that the water effect is not 100% efficient-doubling the water amount provided extra mitigation effect and almost made the 3-sided water-filled cell equal in effect to the water-filled cube[1].

From the Navy's work the following conclusions can be made about application rules:

1. Water placed in the near vicinity of an explosion can absorb energy from the blast and reduce the damage effects of the blast.
2. The amount of water needed for each type of explosive can be calculated based on the ratio of the net explosive weight of the explosive to the weight of water.
3. The placement of the water around the explosive will affect the ability of the water to absorb the blast energy.
4. Safety factors can be applied, increasing the weight of the water placed around the explosive to make up for less than optimum placement of the water around the explosive.

2. Tyndall Explosion Tests and Fire Extinguishing Systems

AFRL's AEF Technologies Division at Tyndall AFB preformed a number of preliminary field tests using water-filled containers around explosive charges. These tests confirmed the findings of the Navy work. Tests showed that by surrounding explosives with water-filled containers on three sides that up to half of the energy of the explosive event could be absorbed with the remainder of the blast wave being directed and dissipated upwards. In other tests water containers were placed only on one side of the explosive and the resulting reduction in the pressure wave was measured. The tests confirmed the findings of the Navy's work. The AEF Division proposes doing large-scale tests to determine effects of scale of the water concept theory[4].

Also at Tyndall AFB, AFRL's Fire Research Group has developed and tested an ultra high-speed fire extinguishing system (AFPDS) for protection of workers in the Army's munitions assembly plants. Phase I of the project involved the development and testing of the AFPDS, showing it to be capable of detecting and extinguishing munitions fires in milliseconds. In the project a prototype system was built using dual-band infrared (IR) and combination ultraviolet /infrared optical fire detectors, high-speed pressurized water discharged from 10 liter (L) and 30L spheres, and follow-on pressurized water from standard nozzles as found in existing plant and arsenal systems. Follow-on water was supplied from a 400-gallon tank pressurized to 150 pounds per square inch (psi)[2].

During Phase I testing of the AFPDS, a number of pyrotechnic compounds were tested. In every case - over 100 fire tests - the AFPDS was able to detect and successfully extinguish each of the burning materials. The AFPDS response time averaged 8 milliseconds (ms) - 6 ms for detector response and 2 ms for sphere discharge response[2].

Phase II of Tyndall' s AFPDS project was designed to evaluate the AFPDS in an operational environment. The AFPDS was to be tested in real-life situations like those found in plants and arsenals involving such processes as screening, sawing, drying, pressing, extrusion, and pouring of the pyrotechnic compounds. An actual powder-charging machine from an assembly plant was shipped to Tyndall' s laboratory for testing. Additionally, a mock workstation was developed for running tests of the AFPDS. Additional compounds-three new pyrotechnics and four new propellants-were also tested in these real-life situations during the Phase II project. During the Phase II project spectral emission characteristics of the various pyrotechnic compounds were measured during burn tests. A Midac Fourier Transform Infrared (FTIR) Spectrometer was used in the collection of these spectral emissions. These data were collected in order to better adjust the measurement parameters of the detectors to optimize their performance[3].

The AFPDS was successfully installed and operated over the various real-life mockups tested in the Phase II project. In every case the AFPDS successfully extinguished the burning pyrotechnic compounds and propellants in the simulated workstation. The AFPDS improvement of reliable detection and extinguishment time over existing systems is faster than any existing system[3]. This system detects and responds to fire situations faster than the eye can see the events occurring.

B. Potential Applications

The concept Active Water for Effective Suppression of Munitions Explosions (AWESOME) would combine aspects of the various research efforts noted in the previous sections. The system would detect an explosion event and would actively respond to it by triggering a projected release of water at the explosion or in the path of the pressure wave. This released blast of water would stop the explosion shock wave propagation at that point and would mitigate the blast effects at the specific point where protection from an explosion is desired.

In those areas where the likely of an explosion is possible, the system would have installed detectors directed at the point of possible explosive events. The system would have pressurized-water reservoirs placed in the immediate area where they could discharge a blast of pressure-driven water at an explosion event when triggered by the detectors. The discharge points of the water reservoirs would be directed in such a way as to dissipate the explosion's shock wave and flame front as it approached the area needing to be protected. The field tests of explosion events showed that by placing the water containers in certain configurations around the explosion point that the shock wave resulting from the explosion was directed in various directions or dissipated at certain points. Thus, a water-blast mitigation system such as the envisioned AWESOME could be placed at a certain point and directed in a specified direction to dissipate an explosion' s shock wave and thereby protect a specific item, point, or feature.

Two possible scenarios where the AWESOME could be employed in explosion protection are outlined in the following paragraphs. The initial scenario describes a situation where an accidental explosive event may be likely to occur and the AWESOME protection is installed to protect against such situations. The second scenario describes possible uses of an AWESOME in anti-terrorist situations where the system is deployed to protect against purposely-set explosives.

1. Scenario One

In an ammunition storage bunker that is divided into various areas with each area having munitions stored in it, the AWESOME could be positioned in corridors connecting these separated storage areas. As the situation now exists, an explosive event occurring in one of the storage areas could send a pressure and blast wave through the connecting corridors that could set off additional explosions in the other storage areas of the bunker. With the AWESOME in place, sensors would detect the blast and the pressure wave initiating in a storage area and traveling down a corridor. This signal would cause the AWESOME to respond by releasing a pressurized blast of water spray directed into the corridor at the approaching pressure wave. This water blast would act to dissipate the force of the explosion propagating through the corridor and could, thereby, protect the adjacent munitions storage areas from chain-reaction explosions.

2. Scenario Two

In areas where terrorist activities may be a possibility, the AWESOME could be placed to protect entrances, gates, hallways, buildings, or structures from the full effects of an explosive detonation. An example of this might be the gate area of a U.S. Embassy, where the AWESOME was installed to protect the gate area from an explosive device placed in a car or truck in front of the facility. In the event of an explosion, the high-speed detectors would trigger the high-speed discharge of a pressurized-water blast in front of the explosion shock wave. As noted in the earlier scenario, the water blast would absorb the shock wave's energy and would dissipate the explosion's effects as the front edge of the blast wave approached the entrance gate.

Because of the nature of a propagating shock wave-it radiates out from the explosion source in all directions equally - the AWESOME can be positioned at any point along this circumference to protect a specific area or point along that circumference. Thus, the whole circumference does not need to be protected. This allows the system to be installed with anticipated design requirements applicable to specific applications. In Scenario two, for example, the possible approach points would be known where vehicles could get close to the gate. Detectors could be positioned to view these possible approach points so that in the event of a detonation at one of these anticipated approach points, the required water discharge release could be timed to achieve the best dissipation effect of any explosion occurring. Release points for the water discharge could be designed and placed around the gate area to provide coverage for the best protection of the entrance gate from the anticipated explosion.

Recent field-tests done at Tyndall AFB showed that the shock wave of an explosion is definitely directed by the physical barriers present around the explosion. A small three-sided berm placed around the point of the explosion resulted in shock wave pressures at the opening of the berm being 10 times the shock wave pressures opposite the open side of the berm. Pressures on the sides of the three-sided berm lay between the pressure extremes of the two ends[5]. These data show that the shock wave blast is a phenomenon that can be manipulated by the placement of barriers. Now the research work needs to continue to make these barriers out of designable water blast barriers that are placed in the path of explosion shock waves as the result of detectors seeing an explosion and reacting to it in a timely manner-the AWESOME concept.

C. APPROACH

A prototype flame detector capable of detecting explosions in microseconds was developed at Tyndall during Phase II AFPDS evaluations. This detection system was tested against explosions and was proven fast and effective. The speed of this detector could allow an active mitigation system to detect an explosion in the time required to trigger an active explosion mitigation system. Since his technology was proven, the decision was made to concentrate efforts on designing and initiating active water mitigation systems.

Active water mitigation systems have potential to protect equipment, facilities and personnel in areas where deflagrations or detonations can occur. Current water discharge systems cannot provide coverage in a timely manner to mitigate these events. Therefore, previous work mainly concentrated on static water filled barriers to determine effects of suppressing or mitigating blast pressures.

This work effort concentrated on designing an active water discharge system that could move large masses of water up to and exceeding 300 feet per second.

D. SYSTEM DESIGN

The concept for a metal hemisphere extinguisher with a rubber diaphragm was developed to discharge large quantities of water as fast as possible. The 12-inch diameter hemisphere was filled with water and pressurized to a point below the burst pressure (determined by testing) of the rubber diaphragm. Figure 1 shows a concept drawing of the hemisphere. One or more explosive actuators (Figure 2) were inserted into the top of the hemisphere to provide initiation of water discharge. The actuators used were manufactured by Fenwal Safety Systems and varied from test to test, but all contained 0.4 or 0.8 grams of PETN.

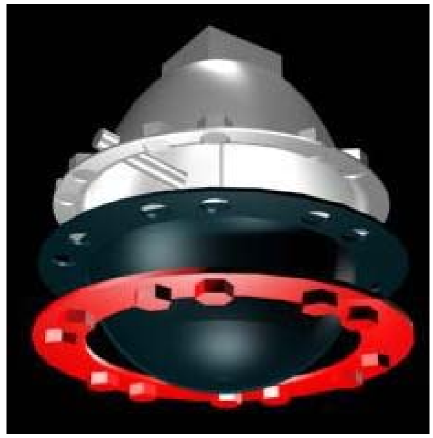

Figure 1: Hemisphere Extinguisher Concept

The hemisphere was constructed out of 1/8” stainless steel. A ½” stainless steel flange was welded to the bottom of the hemisphere (Figure 3). This flange mated with a ¾” stainless steel flange and the rubber diaphragm was inserted in between.   To alleviate water leaks at high pressures, several methods were evaluated. The best method included scoring the flange surface in three radial patterns to create teeth to grab and hold the diaphragm. Also, a cork material was placed around the flange to stop water leaks. The hemisphere was mounted to the wall using two steel brackets designed to counteract the immense force of the system discharge.

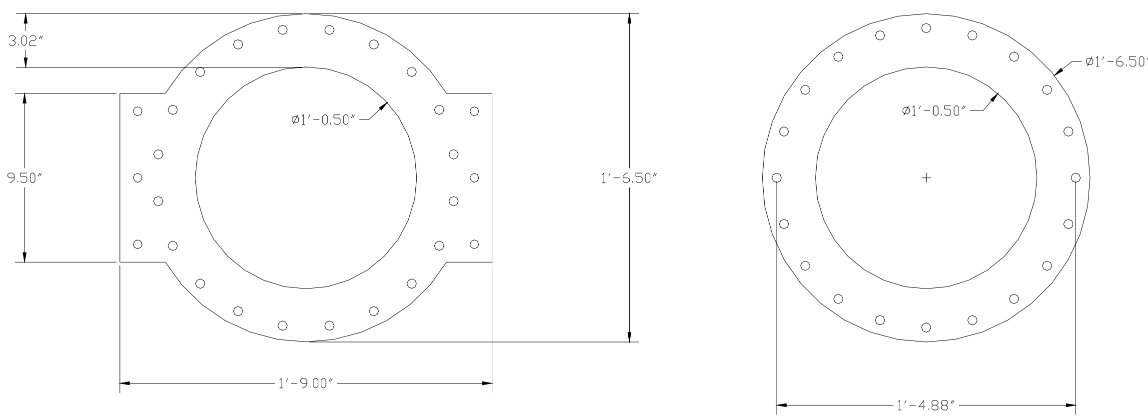

Figure 3: ¾” Bolt-on Flange (left) and ½” Hemisphere Base (right)

The rubber diaphragms used varied from test to test depending on initial system pressures desired. The first tests required internal pressures below 30 psi. For these tests rubber sheeting 1/16” and 1/8” were used. Later as pressures were increased, 3/16” reinforced rubber was used for the diaphragm material. In some tests, the rubber was scored in a pie shape before the test to produce predictable opening of the diaphragm.

As testing progressed, the same hemisphere was used, however the internal water was kept at atmospheric pressure and the explosive charge was increased. PETN explosives (25g) in a moldable form were placed on the inside of the hemisphere to provide the force needed, in a shape charge effect, to propel the water out of the extinguisher (Figure 4). The same explosive actuator was used as in previous tests to initiate the PETN.

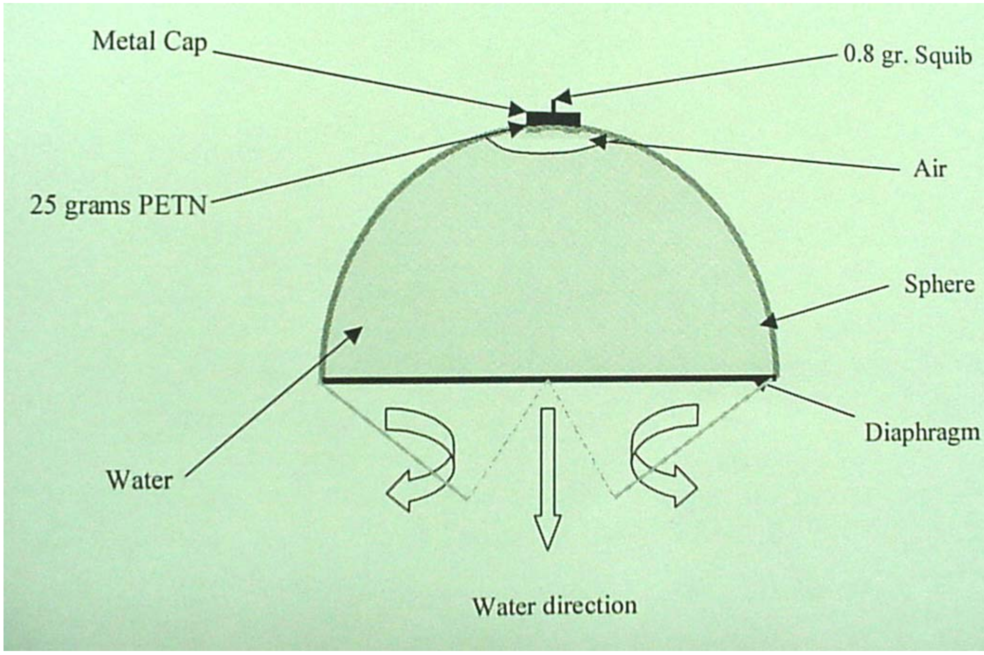

Figure 4: Hemisphere with PETN Explosive Charge

II. TESTING

Test efforts for this program concentrated on developing methods for delivering large quantities of water at high velocities. Detection of explosions and initiation of the water suppression was not addressed in this test effort. The initial concept for the hemisphere extinguisher was to fill the device with water and inflate the rubber diaphragm with water pressure. An explosive charge, inside the hemisphere, would then be initiated to increase the internal pressure above the burst pressure of the diaphragm, commencing the discharge of water.

Evaluations began with non-reinforced rubber diaphragm material that allowed for internal water pressures up to 30 psi. After installing the diaphragm, the system was filled with water until all air was displaced. The system was sealed, and water was added until the desired internal pressure was achieved. The explosive actuator was added to the system last. Several tests were conducted with this system configuration (see Figures 5 and 6). After system initiation, axial water velocities were consistently measured well below 100 feet per second with our goal velocity of 300 feet per second, minimum. It was also observed that the rubber diaphragm opened 3-5 milliseconds after system initiation, and upon further inspection after the tests it was noted that the location and shape of rubber failure was different each test.

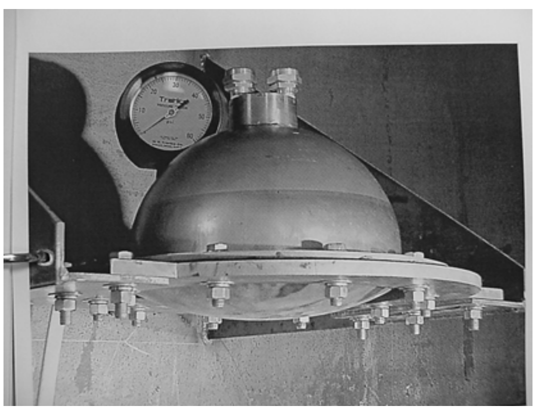

Figure 5: Hemisphere

Figure 6: Hemisphere

It soon became apparent that higher water pressures or larger amounts of explosives would be required to produce desired results. Higher water pressures were explored first.

To facilitate higher water pressure in the hemisphere extinguisher, the rubber diaphragm material was changed to 3/16" fiber reinforced rubber. Modifications were made to the hemisphere flange to prevent leaks. The system was filled as before and pressures were increased to 200 psi with no leaks and above 200 psi with minor leaks around the bolted flange. The explosive charge inside the system was slightly increased by discharging two to five 0.8 gram explosive actuators at once. Water velocities were increased, however it was evident that this approach would not meet the goal.

A new approach was then taken with explosive force and decreased water pressure. A concept drawing of the design is shown in Figure 4. Water pressure in the system was maintained at atmospheric and the quantity of explosives in the extinguisher was increased. 25 grams of moldable PETN explosives were placed in a shape charge on the inside of the hemisphere (see Figure 7). A plastic membrane was installed as the diaphragm with a pre-scored rubber disk below to protect the plastic membrane and control the water pattern exiting the extinguisher (see Figure 8). The system was filled with water until all air was evacuated and was then sealed with no pressure on the system. A blasting cap was used to initiate the PETN explosives.

Figure 7: PETN charge inside extinguisher before adding water.

Figure 8: Pre-scored rubber disk and lower flange of Hemisphere extinguisher

This design provided the force needed to move the water at greater velocities than previously achieved. Water velocity was measured at >230 feet per second.

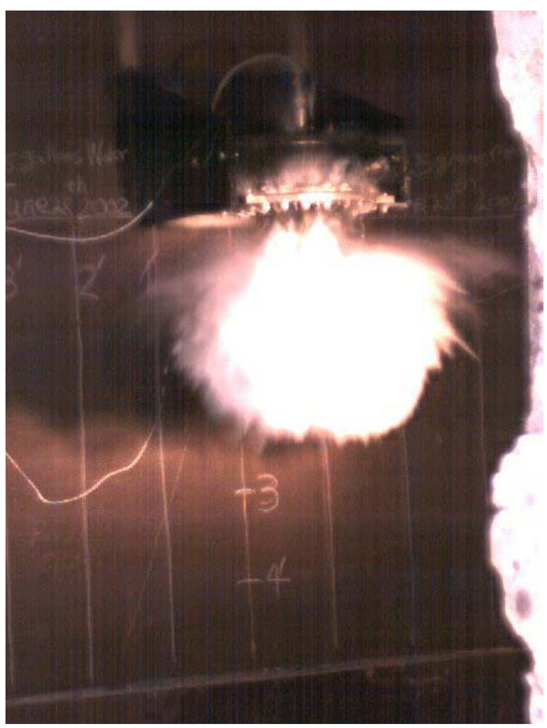

Figure 9: Hemisphere Discharge with PETN Explosive Charge

III. CONCLUSIONS & RECOMMENDATIONS

The test effort ended by discharging water from the hemisphere extinguisher at a velocity of >230 feet per second. While under the goal of 300 feet per second, this result was deemed successful. Several methods were evaluated that minimized the quantity of explosive material required to move the water at desired velocities. However, these methods were proven unsuccessful in this test series.

Earlier work with the AFPDS showed that a small mass of water could be discharged at high velocities, powered by stored energy in the form of compressed gas. Velocities from a three-inch orifice of the AFPDS exceeded 160 feet per second. The goal of delivering a large mass of water at high velocities was verified on a small scale in this effort.

Future efforts should build upon the lessons learned in this program. The implementation of explosively driven water should be optimized to determine maximum water velocities achievable and determine that the concept can be scaled up for larger mass flow. The shape of the water spray will also have to be optimized to effectively mitigate energy from deflagrations and detonations. Methods to increase water velocities and optimize water spray patterns include increasing explosive quantities, using shape charge expertise and developing steel, cone-shaped discharge orifices.

Evaluations against pyrotechnics and explosives will determine the level of protection from explosively driven water sprays. Assess fire protection of mixing bowl operations for pyrotechnics and infrared flare manufacturing operations to gauge the suppression effects of the developed system.

IV. REFERENCES

1. Keenan, W. A., and Wager, P. C., "Mitigation of Confined Explosion Effects by Placing Water in Proximity of Explosions," 25th DoD Explosives Safety Seminar, Anaheim Hilton Hotel, Anaheim, California, 18-20 August 1992.

2. Carr, V., Cozart, K. S., and Wells, S. P., "Advanced Fire Protection Deluge System, Phase I Report" (AFRL-ML-TY-TR-1998-4526), for the U.S. Army Defense Ammunition Logistics Activity (AMSTA-AR-AL), Picatinny Arsenal, NJ, by Air Force Research Laboratory, Materials & Manufacturing Directorate, Airbase & Environmental Technology Division, Tyndall AFB, FL, July 1998.

3. Wells, S. P ., Carr, V ., and Cozart, K. S., "Advanced Fire Protection Deluge System, (AFPDS) Phase II Report" (AFRL-ML-TY-TR-2000-4521), for the U.S. Army Defense Ammunition Logistics Activity (AMSTA-AR-AL), Picatinny Arsenal, NJ, by Air Force Research Laboratory, Materials & Manufacturing Directorate, Airbase & Environmental Technology Division, Tyndall AFB, FL, 2000.

4. Barthold, B. R., "Water Blast Mitigation for Munitions Storage," Memorandum for HQ USAF/ILE and attachments from HQ AFCESA/CC, 21 April 2000.

5. Dover, D., and Hill, G., “Blast Mitigation preliminary results from 27 Jun 2001 and 13 July 2001 field tests”, by Air Force Research Laboratory, Materials & Manufacturing Directorate, Airbase & Environmental Technology Division, Tyndall AFB, FL, July , 2001.